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MEMORANDUM REPORT No. 1020

JULY 1956

Aerodynamic Properties Of 60-MM Mortar Shell, T24

EUGENE D. BOYER

DEPARTMENT OF THE ARMY PROJECT No. 5B03-03-001
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0108

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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MEMORANDUM REPORT NO. 1020

EBoyer/rf
Aberdeen Proving Ground, Md.
July 1956

AERODYNAMIC PROPERTIES OF 60-MM MORTAR SHELL, T24

ABSTRACT

The spin histories, drag, and yaw properties of the 60-mm T24 mortar shell are presented. These data were obtained from Transonic Range firings.

TABLE OF SYMBOLS AND COEFFICIENTS

A	axial moment of inertia
B	transverse moment of inertia
cm	center of mass
d	diameter
M	Mach number
K_D	drag coefficient
K_M	moment coefficient
K_{MA}	moment coefficient due to cross acceleration (Reference 5)
K_L	lift coefficient
K_H	damping coefficient
ϕ'	roll rate (deg./ft.)
$\lambda_{1,2}$	yaw damping rates
δ	sine of the angle of yaw
$\overline{\delta^2}$	mean squared yaw
δ_e^2	$K_{10}^2 + K_{20}^2 + \frac{\phi_1' K_{10}^2 + \phi_2' K_{20}^2}{\phi_1' - \phi_2'}$ effective squared yaw for K_M
C_{L_δ}	roll moment derivative due to canted surface
C_{L_p}	roll moment derivative due to rolling velocity
ρ	density of air
μ	total velocity

INTRODUCTION

In connection with a mortar project of the research division of the Budd Company, Picatinny Arsenal requested that the Ballistic Research Laboratories study the aerodynamic properties, particularly roll, of the 60-mm T24 mortar shell. The shell was tested with three different fin assemblies: non-canted fins, fins with two degrees of cant on the after section, and fins with four degrees of cant on the after section (Figure 7a). The firings were conducted in the Transonic Range. This report is a brief account of the firings and the results obtained.

EXPERIMENTAL PROCEDURE

The shell were launched from a trigger-fired 60-mm mortar tube mounted in a 105-mm howitzer field mount (Figure 7b). At normal velocities and the elevation angles necessary to fire through the Transonic Range instrumentation the mortar shell would hit within the range building. Hence it was necessary to fire the program from within the range building and forego some of the instrumentation. For the shell to enter the instrumentation, it was necessary to start its flight approximately nine feet above the range floor. To obtain this height, the field carriage was loaded in the rear of a 2-1/2 ton shop truck (Figure 8) and the program fired from a point between the first two groups of range stations [6]. As a result only twenty of the twenty-five spark photographic stations could be utilized. Timing cables were rearranged to permit thirteen time-of-flight measurements to be taken.

To determine the roll histories of the shell, sets of three yaw cards were placed at the beginning and end of the shadowgraphic instrumentation. The shell were equipped with two "pop-out" pins which remained within the shell's contour during launching and emerged when the projectile entered free flight. The pins extended beyond the major diameter and cut the yaw cards. From these cuts the roll history of the projectile was determined. To extend the roll measurements to longer ranges (1800 feet) it was necessary to fire a few rounds outdoors. The higher angle trajectories required for the longer ranges could not be fired from inside the range building.

Nineteen rounds were fired through the range and eleven outdoors. All of the rounds were fired at a nominal velocity of 500 fps. Twelve of the nineteen shell fired through the range had trajectories suitable for determining aerodynamic data. Roll data at 1800 feet were obtainable from only four of the eleven shell fired outside the range. A sketch of the shell and its physical measurements are given in Figure 6.

EXPERIMENTAL RESULTS

A. Drag

The drag coefficient does not appear to be noticeably affected by the presence of different fin cants. Any differences that may exist[3] are well within the scatter of drag data expected from round to round variation with production shell. However, a definite variation of drag with yaw level is evident (Figure 1) and, fitting a least squares to $K_D = K_{D_0} + K_{D_{\delta^2}}\delta^2$ yields:

$$K_{D_0} = 0.0761 \pm 0.0008$$

$$K_{D_{\delta^2}} = 2.1 \pm 0.4$$

where δ is in radians. All errors are standard errors.

B. Yawing Motion

The values of the yaw properties for each round are given in Table 1. As seen in Figures 2 and 3 the moment coefficient, K_M, and the lift coefficient, K_L, are influenced by the magnitude of the yaw. These coefficients have been reduced to zero-yaw values by the ralationships:

$$K_M = K_{M_0} + K_{M_{\delta^2}}\delta_e^2$$

$$K_L = K_{L_0} + K_{L_{\delta^2}}(K_{10}^2 + K_{20}^2)$$

where righting moment $= \rho d^3 \mu^2 \left[K_{M_0} + K_{M_{\delta^2}}\delta^2\right]\delta$

$$\text{lift force} = \rho d^3 \mu^2 \left[K_{L_0} + K_{L_{\delta^2}} \delta^2 \right] \delta$$

and $\delta_e^{\,2}$ is a function of the amplitude of the two yaw components and the rates as defined in the Table of Symbols and Coefficients. In Reference 4 it is shown that if non-linearities in aerodynamic forces and moments are representable by cubics in yaw, then K_M vs. δ_e^2 and K_L vs. $K_{10}^{\;2} + K_{20}^{\;2}$ form linear combinations.

Fitting by least squares gives: *

$$K_{M_0} = -\,0.84 \pm 0.02$$

$$K_{M_{\delta^2}} = -\,10 \pm 2$$

$$K_{L_0} = 0.91 \pm 0.04$$

$$K_{L_{\delta^2}} = 18 \pm 5$$

when yaw is expressed in radians.

The yaw damping coefficient, $K_H - K_{MA}$ was poorly determined due to the presence of small asymmetries in the shell and no correlation with yaw was apparent. A value of $K_H - K_{MA} = 8.0$ seems representative of this shell. The amplitude of yaw damps fifty per cent in approximately two cycles of yaw, a distance of 300 feet.

C. Röll

The roll data, as determined from yaw card measurements, are given in Table 2 and Figures 4 and 5. Slight inconsistencies in performance from round to round, as shown in Table 2, are probably due to minor fin misalignments and manufacturing variations in the cants of the trailing edges of the fins. Yaw card measurements for the shell with the uncanted fins indicated that the shell were not spinning significantly.

---

* Tricycle rounds were not included in fitting K_L.

The differential equation of motion of a rolling finned missile for a range trajectory is of the form[1]:

$$\phi'' + C_1 \phi' = C_2$$

The constants were determined from fitting the yaw card measurements and are:

2° cant $\quad C_1 = 0.0014\ (1/\text{ft})$

$C_2 = 0.007\ (1/\text{ft}^2)$

4° cant $\quad C_1 = 0.0017\ (1/\text{ft})$

$C_2 = 0.017\ (1/\text{ft}^2)$

Nominally C_1 should be the same for missiles differing only in fin cant and C_2 should be proportional to the cant. The given C_1's are essentially equal, within the significance of the determination, and in the same sense (on a per degree of cant basis) so are the C_2's. Average values would be:

$$C_1 = 0.00155\ (1/\text{ft})$$

$$C_2 = 0.004\ (1/\text{ft}^2) \text{ per degree of cant.}$$

If one assumes the canted area of the fins to be one-tenth of the total fin area, where the fin area is approximately 2.07 square inches, the aerodynamic coefficients[1] for the 4 degree canted fin are:

$$C_{L_\delta} = .30$$

$$C_{L_p} = -\ .21.$$

Eugene D. Boyer
EUGENE D. BOYER

APPENDIX A

TABLE 1
Aerodynamic Data

Round Number	Fin Cant	M	K_D	K_M	K_L	K_H	$\lambda_1 x10^3$ $(ft)^{-1}$	$\lambda_2 x10^3$ $(ft)^{-1}$	$\overline{\delta^2} x10^2$ $(rad)^2$	$\delta_e^2 x10^2$ $(rad)^2$	K_{10} (rad)	K_{20} (rad)	K_{30} (rad)	N	N_T	S_L (ft)	ε_y (rad)	ε_S (ft)	ϕ_1' (deg/ft)	ϕ_2' (deg/ft)
3599	0°	.424	.0814						.24					12	5					
3600*	0°	.426	.0808	- .816					.25	.13	.029	0	.039	17	8		.003		- 2.21	2.21
3601*	0°	.426	.0789	- .819	.88	11.4	.53	4.22	.22	.23	.035	.018	.017	15	8	.02	.006	.015	- 2.23	2.23
3602*	0°	.424	.0873	- .934	.98	7.0	1.12	2.05	.49	.62	.040	.050	.007	18	8	.03	.010	.008	- 2.38	2.38
3603	0°	.429	.0794	- .894	.91	8.0	2.68	.80	.04	.06	.011	.016		13	7	.01	.003	.007	- 2.23	2.43
3594	2°	.428	.0825	- .870	1.00	5.9	.32	2.47	.41	.55	.048	.037		15	9	.03	.008	.015	- 2.38	2.22
3597	2°	.427	.0818	- .858	.95	12.4	2.95	2.19	.24	.27	.030	.030		17	11	.02	.010	.014	- 2.33	2.22
3598	2°	.426	.0833	- .936	.96	7.6	.72	2.69	.47	.62	.059	.025		19	9	.03	.009	.021	- 2.40	2.36
3589	4°	.427	.0816						.16					12	6					
3591	4°	.434	.0840	- .924	.93	8.0	- .37	3.90	.43	.61	.057	.028		16	9	.03	.005	.018	- 2.41	2.35
3592	4°	.423	.1064	-1.071	1.12	7.4	1.32	2.14	1.38	2.14	.093	.075		15	10	.05	.008	.019	- 2.61	2.49
3593	4°	.432	.0947	- .906	1.17	9.5	- .70	4.96	.92	1.24	.087	.026		13	8	.05	.006	.011	- 2.47	2.24

K_{10} size of nutational yaw arm at mid-range
K_{20} size of precessional yaw arm at mid-range
K_{30} size of tricyclic yaw arm at mid-range
N number of yaw stations
N_T number of timing stations

S_L radius of swerve at mid-range
ε_y error in yaw fit
ε_S error in swerve fit
ϕ_1' turning rate of nutational arm
ϕ_2' turning rate of precessional arm

* Tricyclic yaw reductions were required on these rounds[2]

TABLE 2

Roll Data
(deg/ft)

Roll Rate For Various Rounds

Fin Cant 2°

Distance Down Range (ft)	3594	3595	3596	3597	3598	Field Firings	
35	0	.1	.4	- .1			
50	.4	.1	0	.1			
335	1.3	1.5	1.0	1.3	1.6		
615	2.6	2.4	2.0	2.5	2.3		
630	2.6	2.8	1.9	2.6	2.5		
680	2.6	2.9	1.9	2.7	2.5		
725	2.9	3.4	2.4	2.8			
740	3.0	3.1	2.3	3.0			
1775						5.2	6.6
1790						5.6	7.2

Fin Cant 4°

Distance Down Range (ft)	3588	3589	3590	3591	3593	Field Firings	
35	.1	.6	.3	.2	0		
50	.2	.3	.3	.5	.3		
335	2.3	2.4	2.0	2.8	3.4		
615	4.0	4.5	3.7	4.1	6.0		
630	4.3	4.6	3.7	5.0	6.1		
680	4.9	4.9	3.8	4.9	6.6		
725	5.0	5.0	4.0	5.1	6.8		
740	5.2	5.3	4.5	4.5	6.9		
1775						12.8	
1790						14.3	14.3

APPENDIX B

Graphs and Photographs

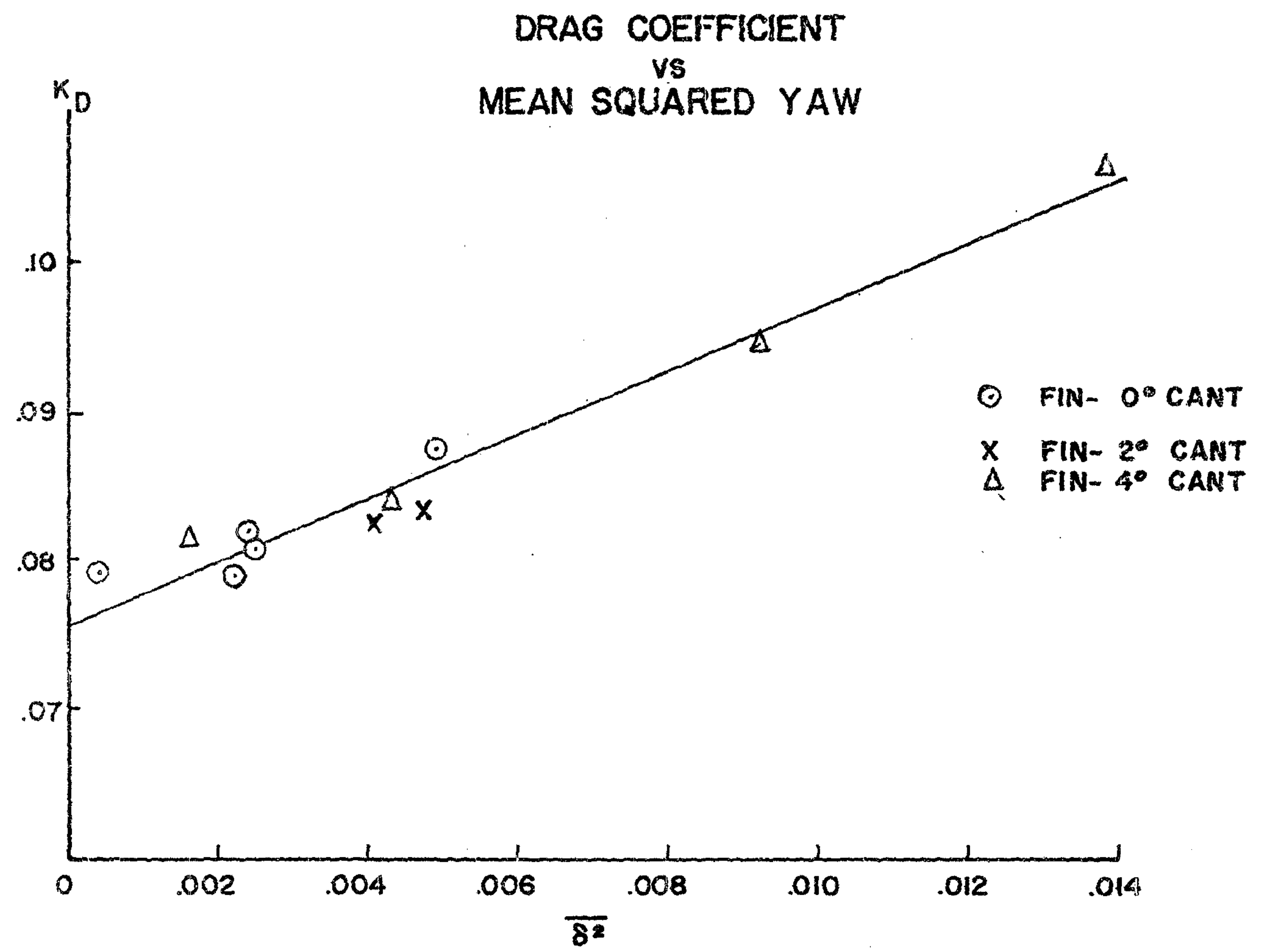

DRAG COEFFICIENT
VS
MEAN SQUARED YAW
K_D
.10
.09
.08
.07
0
.002
.004
.006
.008
.010
.012
.014
$\overline{\delta^2}$
FIN- 0° CANT
FIN- 2° CANT
FIN- 4° CANT

FIG. I

MOMENT COEFFICIENT

VS

δ_e^2

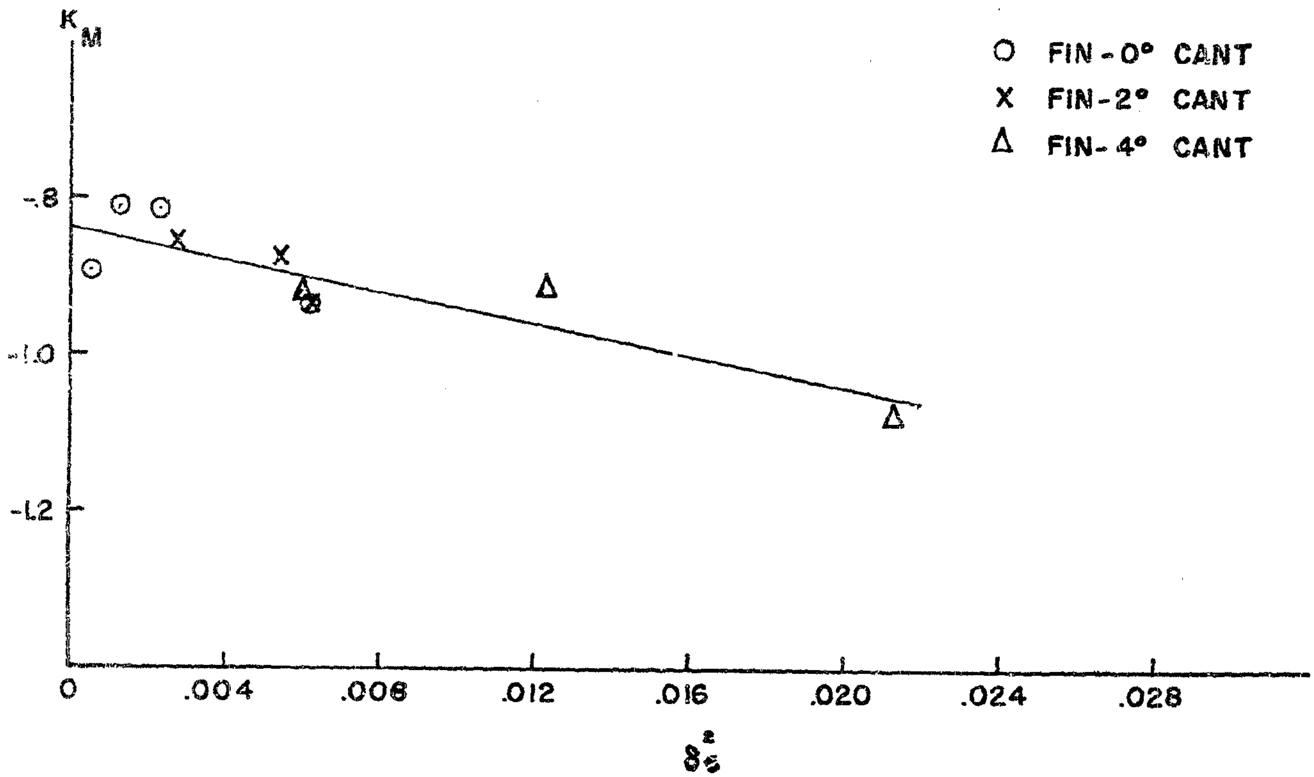


FIG. 2

LIFT COEFFICIENT

VS

$K_{10}^2 + K_{20}^2$

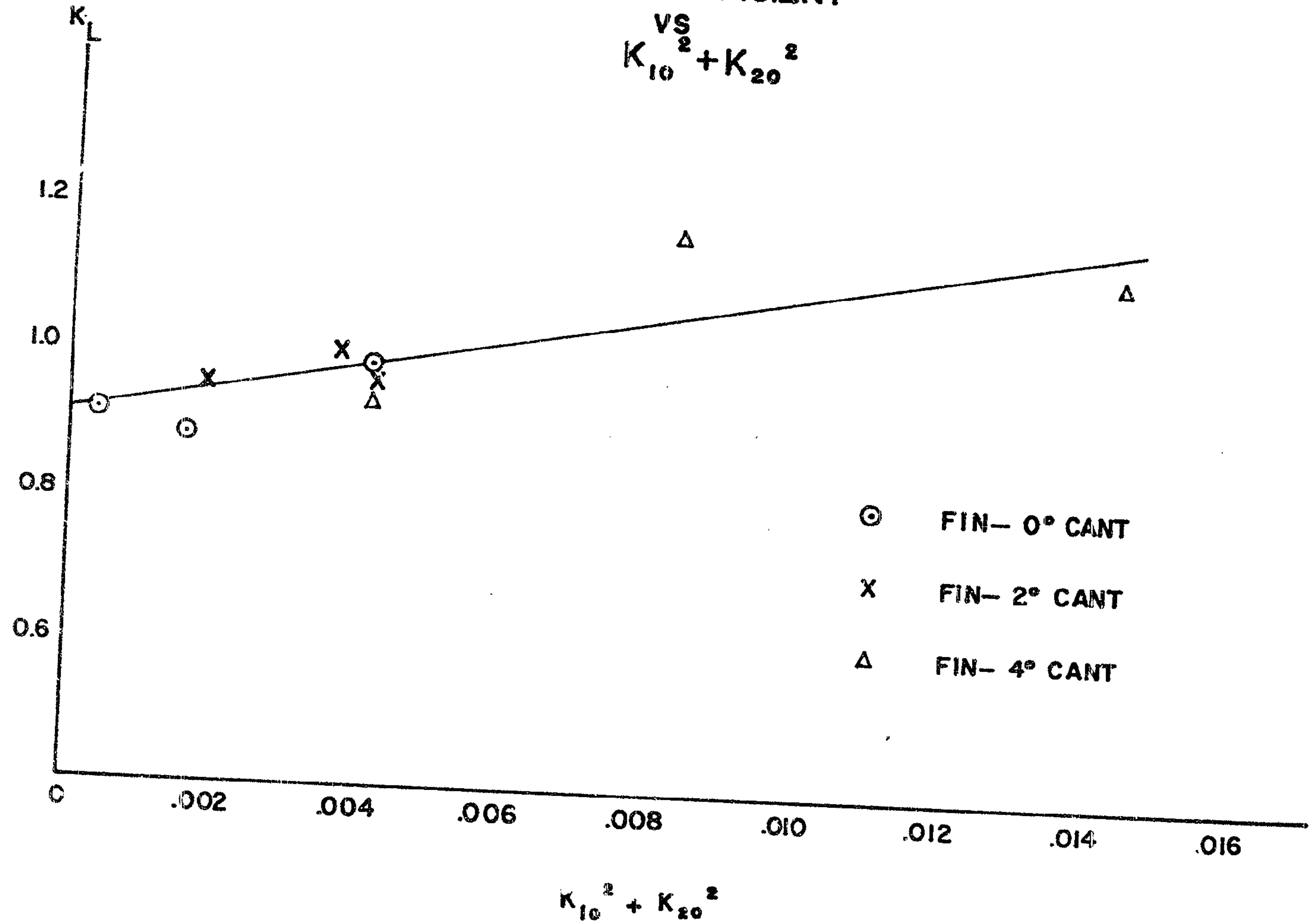


FIG. 3

ROLL RATE
vs
DISTANCE DOWN RANGE
FIN-CANT 2°

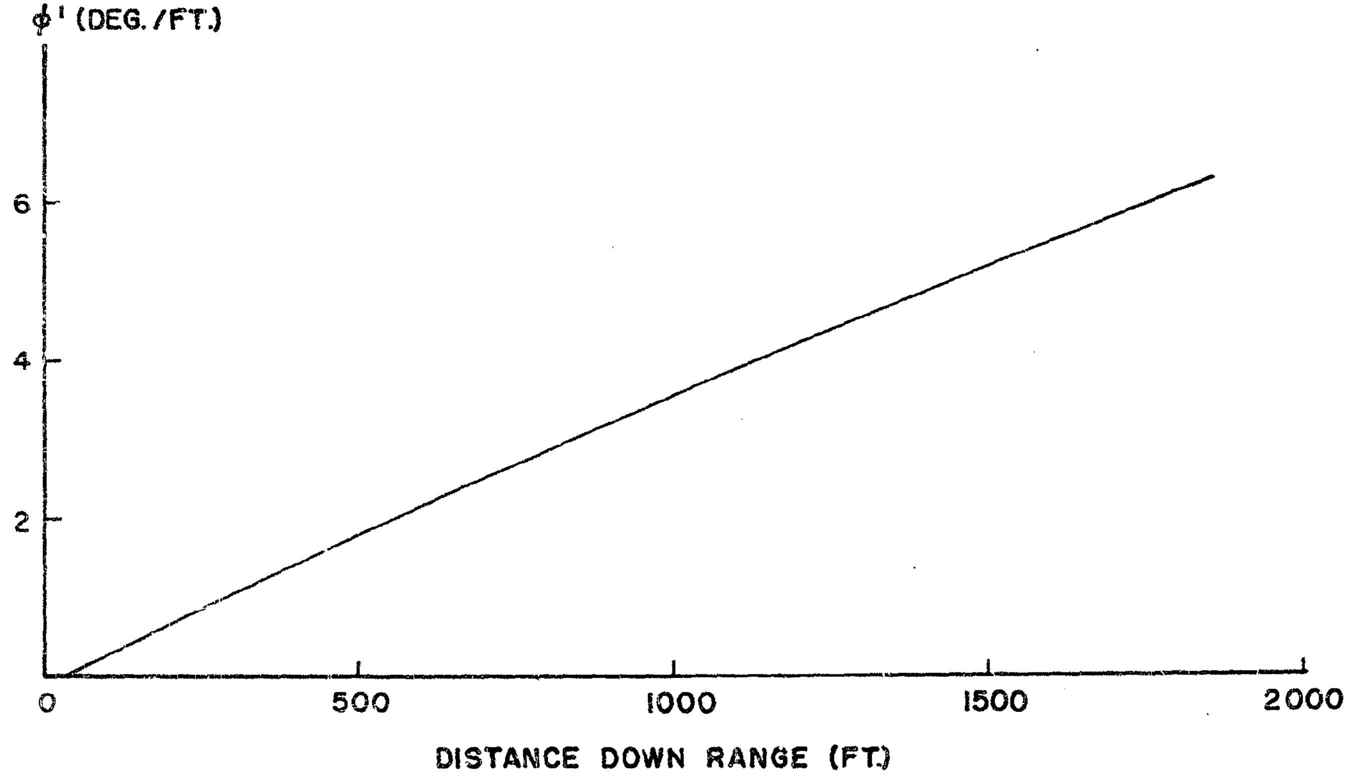


FIG. 4

ROLL RATE
vs
DISTANCE DOWN RANGE

FIN-CANT 4°

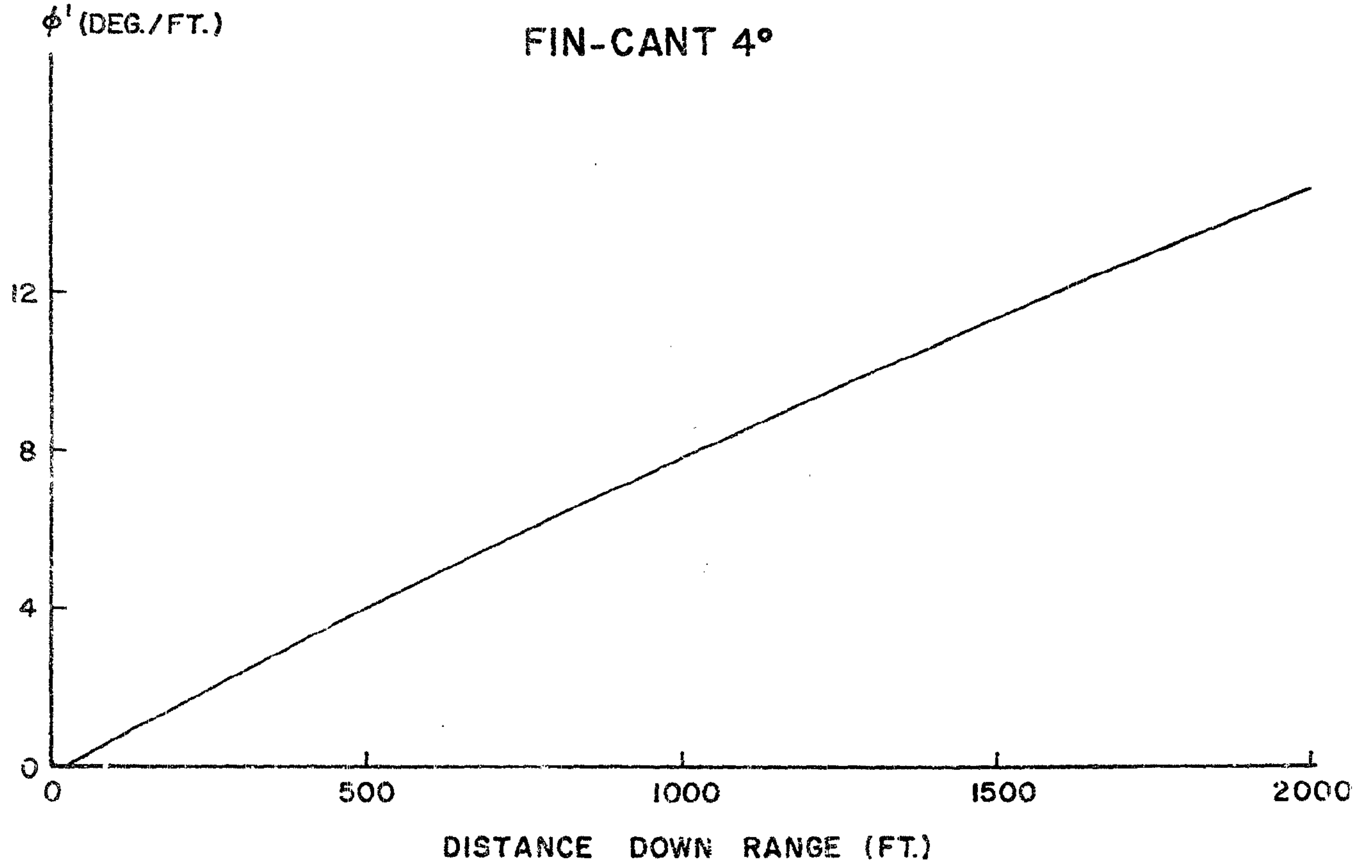
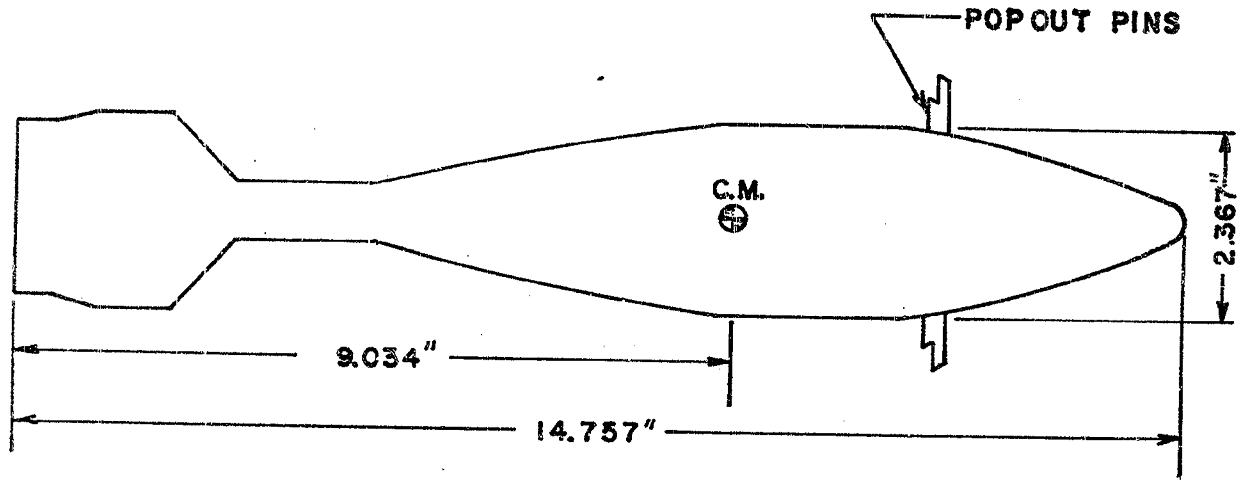


FIG. 5

60 MM MORTAR SHELL T24



A = 2.734 LB-IN²
B = 43.20 LB-IN²
m = 4.05 LBS.

FIG. 6

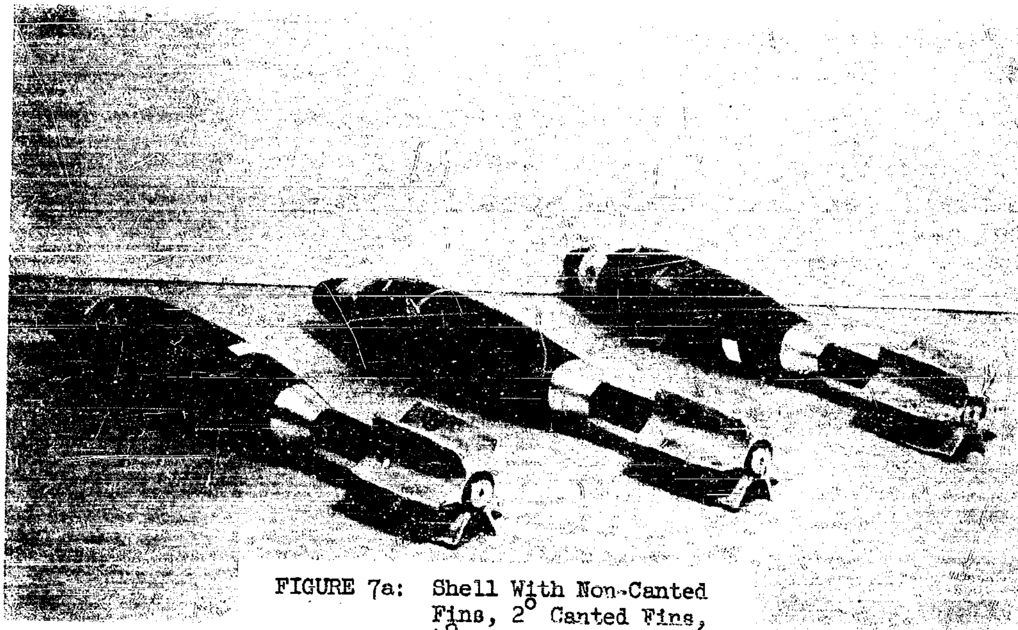


FIGURE 7a: Shell With Non-Canted Fins, 2° Canted Fins, 4° Canted Fins

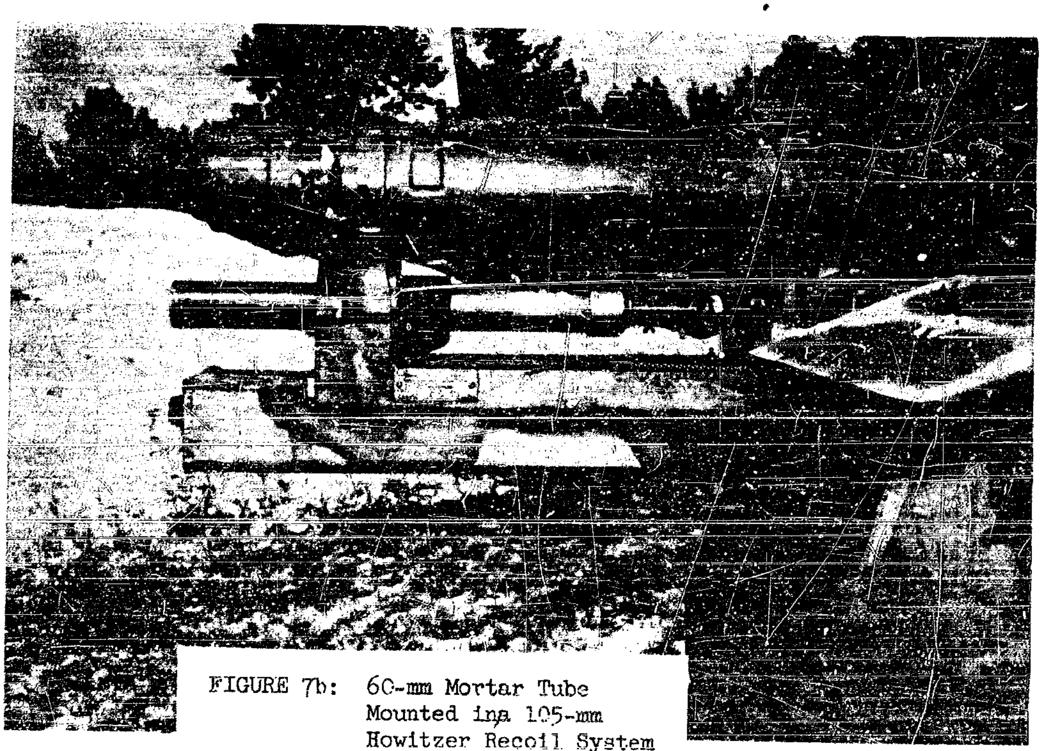


FIGURE 7b: 60-mm Mortar Tube Mounted in a 105-mm Howitzer Recoil System

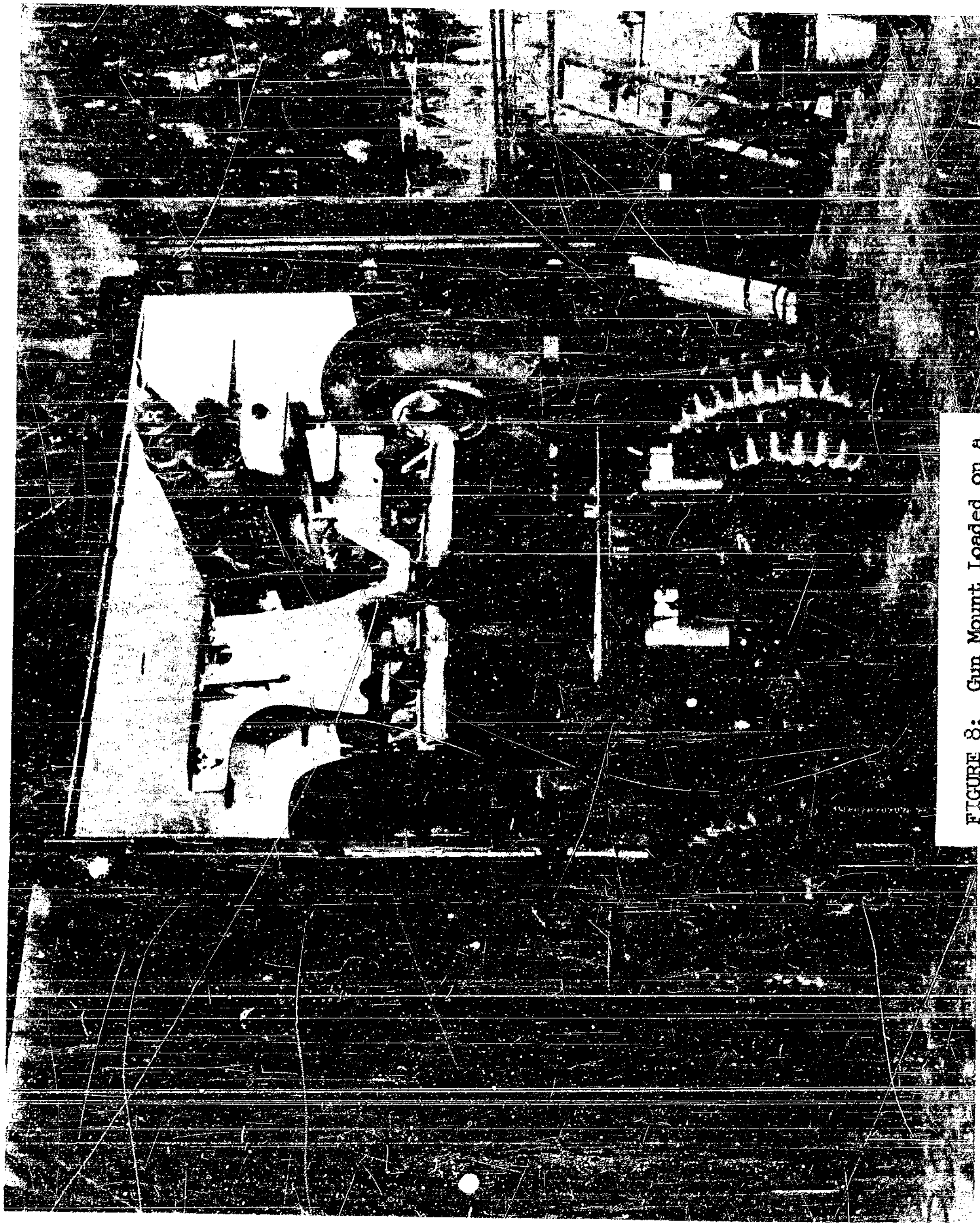


FIGURE 8: Gun Mount Loaded on a 2-1/2 Ton Shop Truck

APPENDIX C

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